Chapter 6.
Conclusions and Recommendations

Introduction

Geologic and Geomorphic Setting and Subreaches of Study Area

The San Joaquin River enters the Great Central Valley, an asymmetrical basin whose axis is offset to the west side of the basin, at Friant, the head of the study area which extends for about 150 miles downstream to the confluence with the Merced River at Hills Ferry. The basin lies between the crests of the Sierra Nevada and the Coast Ranges and extends from the northern boundary of the Tulare Lake basin to the Delta near Stockton. The bulk of the flows in the river is derived from rainfall and snowmelt in the Sierra Nevada. For the purposes of this report, the study area was subdivided into 5 reaches and 2 subreaches on the basis of the geomorphological characteristics of the valley and river as well as hydrological changes that have been imposed on the system.

Subreach 1A extends from Friant Dam (RM 267) to Herndon (RM 243). In this subreach, the river is confined by at least two terraces that formed as a result of river incision into the Pleistocene-age alluvial fan that had prograded out into the valley. The river and the terraces in this subreach have been extensively mined for sand and gravel. Subreach 1B extends downstream to the terminus of the confining terraces at Gravelly Ford (RM 229) and essentially concludes at the head of the flood control project levees. Subreach 2 extends downstream to Mendota Dam at RM 205. The river flows down the modern alluvial fan surface, whose intersection point is located at the downstream terminus of the terraces at the head of the reach. Remnants of the modern alluvial fan distributary channels can be seen outside of the levees that flank the river. The San Joaquin River has its highest sinuosity in this reach because it flows down the dip slope into the axis of the basin. The Chowchilla Bypass Control Structure is located within this reach at RM 216. In Subreach 3 between Mendota Dam and Sack Dam (RM 182), the river flows north in the low-gradient axis of the basin. In this subreach, the moderately sinuous, single-thread river conveys the flows imported by the Delta-Mendota Canal. The river and its floodplain are confined by an alluvial terrace to the west and the distal margins of the coalesced alluvial fans of the eastside tributaries to the east. Local levees and constructed irrigation canals border the river throughout this subreach.

Within subreaches 4 and 5, the San Joaquin River historically had a multichanneled, anabranched planform that enabled it to more efficiently convey flows and sediment through the flood basin in coexisting channels and sloughs. The floodbasin and the anabranched channels formed in response to the base level control imposed by the Merced River alluvial fan that prograded out onto the valley floor from the Sierra Nevada. Subreach 4A extends from Sack Dam to the Sand Slough Control Structure at RM 168. Subreach 4B extends downstream to the Bear Creek confluence, which is also where the Eastside Bypass flows are returned to the San Joaquin River at RM 136. Subreach 5 extends downstream to the confluence with the Merced River at Hills Ferry (RM 118), where the individual channels and sloughs combine to again form a single-thread river channel.

Major Influences on the San Joaquin River

The morphology of the San Joaquin River and the sloughs was documented in the CDC 1914 hydrographic survey of the river from the Delta to Herndon, performed prior to significant water development, land use changes, and flood control efforts. Since the 1914 survey, the river system and the watershed have been significantly modified.

Development of the water resources within the basin commenced about 130 years ago. Millerton Lake, which was formed by Friant Dam, and the other reservoirs constructed on the eastside tributaries by the Corps since the late 1940s have the capacity to store almost 1 million acre-feet of water. These storage projects have significantly altered the peak flows and the flow durations within the study reach of the San Joaquin River. Additionally, historical flood flows that were derived from the Kings River basin have been significantly reduced as a result of the construction of Pine Flat Dam, which has a storage capacity of about 1 million acre-feet. Except under flood flow conditions, extensive reaches of the river below Friant Dam are now dry for most of the year. Importation of water from the Delta via the Delta-Mendota Canal has maintained a perennial flow regime in the reach of river between Mendota Dam and Sack Dam. Delta-Mendota Canal, in operation since the mid-1950s, was constructed to offset the impacts of Friant Dam on the downstream water users along the San Joaquin River.

Commencing in the 1920s, significant overpumping of groundwater has caused up to 30 feet of valley floor subsidence to the west of the river. Within the study reach, from 1 to 6 feet of subsidence have been documented. The rates of subsidence (about 40 mm/year) were about two orders of magnitude higher than the geologically-driven rate of subsidence (0.25 mm/year) that has been on-going since the Mesozoic.

Local levees and flood control projects were completed along the river between about 1915 and 1930 by local landowners. Between 1959 and 1966, the State of California constructed the Eastside Bypass flood control project with a 50-year level of protection from the Merced River confluence upstream to the Chowchilla Bypass. The system consists of about 190 miles of levees as well as several flow control structures, bypass channels, and associated facilities; it is maintained by the LSJLD. Non-project levees are located between Mendota and just upstream of the Mariposa Bypass.

Construction of Friant Dam and the flood control dam on Little Dry Creek have significantly reduced the inflow of sediment to the study reach of the San Joaquin River. Extensive in-channel mining of sand and gravel in combination with the reduced inflow of sediment has resulted in severe channel degradation between Herndon and Friant Dam.

The major influences identified above are the primary causes of the changes that have occurred along the river. The cause and effect relationships for the individual subreaches are discussed in the next section.

Effects of Major Influences

Geology and Geomorphology

The study area of the San Joaquin River that extends from the Merced River confluence at RM 118 to Friant Dam at RM 267 has been subdivided into 7 subreaches on the basis of geomorphic, hydrologic, and constructed controls (Table 4.1). At the downstream end of the study area, base level control is exerted by the Merced River alluvial fan that has prograded out into the asymmetric San Joaquin valley. Although there is good geological evidence that the entire basin is slowly subsiding, the fan appears to be maintaining base level for the upstream reach of the San Joaquin River at a constant elevation, at least within the period from 1913/1914 to the present (Table 4.5). Over a longer period of time, the anabranching river system located within subreaches 4A, 4B, and 5 argues for a rising base level (Knighton and Nanson 1993, Nanson and Knighton 1996, Nanson and Huang in press). Channel degradation between the Merced River and Vernalis, determined by cross section surveys in 1913/1914 and repeat surveys in 1974, was documented by the USGS (Simpson and Blodgett 1974). However, channel incision below the Merced River confluence does not appear to have extended upstream into subreach 5.

The flood basin of the San Joaquin River (Hall 1887; Appendix D), which is characterized by the anabranching channel system made up of the mainstem river and the major sloughs—Sand Slough, Salt Slough, and Mud Slough—comprises subreaches 5, 4A, and 4B (i.e., Merced River to Sack Dam). Major and minor sloughs in the flood basin east of the San Joaquin River include Buttonwillow Slough, Deep Slough, Lone Willow Slough, Mariposa Slough, and Sand Slough; west of the mainstem river are Middle Slough, Mud Slough, Pick Anderson Slough, Poso Slough, Salt Slough, Santa Rita Slough, and Wood Slough. Historically, rainfall and snowmelt floods were conveyed through the floodbasin, and floodwaters were reported to stand in the overbank areas for 3–5 months per year. Sediment transport continuity was maintained by the hydraulically more efficient anabranched channels (Nanson and Huang in press). Riparian forest stands were located along the channel margins on the natural levees that formed on the mainstem and the sloughs (Appendix C).

The San Joaquin River in subreach 3 (Sack Dam to Mendota) was historically a relatively low sinuosity (Table 4.2), single-thread, meandering channel that was bordered to the west by an alluvial terrace and to the east by the distal margins of the coalesced eastside alluvial fans. The extent of the historical floodplain has also been limited by the construction of local levees and irrigation canals, but can be approximated by the FEMA 100-year floodplain (Figure 1.2). The floodplain was primarily located to the east of the river in subreach 3. Interpretation of channel changes in subreach 3 is confounded by human-induced subsidence and major changes in reach hydrology as a result of upstream dam construction (Friant Dam), reduction of Kings River North and Fresno Slough surface and groundwater contributions, and importation of Delta water via the Delta-Mendota Canal.

Friant and Water Storage Projects

Changes caused by upstream water development projects, implementation of the flood control system, and importation of Delta water have radically altered the flood and mean daily hydrology of the study area. An order of magnitude reduction in the magnitudes of the higher-frequency flood events (2-, 5-, 10-year) has occurred since construction of Friant Dam in the 1940s (Table 3.1). However, lower-frequency flood events (100-year or greater) still pose a threat to the system, which was designed to provide a 50-year level of protection (Hill pers. comm.).

In the post-Friant Dam period, there have been order of magnitude reductions in the mean daily flows as well (Table 3.2). The annual median discharge (Q50) at the Friant gage has been reduced from 1,400 cfs to 140 cfs, and the median discharge in the April–May period has been reduced from 4,500 cfs to 160 cfs. At the Fremont Ford gage (River Mile 125), the annual median discharge has been reduced by about 60% (480 to 200 cfs) and median discharge for the April–May period has been reduced by about 90% (2,400 to 280 cfs). Since 1985, most of the flow during nonflood periods at Fremont Ford is probably of low quality since it is derived from Salt Slough, agricultural tailwater, and groundwater seepage high in dissolved salts.

The major changes in hydrology caused by upstream water development projects have altered the channel capacity–discharge frequency relationship throughout the study area. Under pre-Friant conditions, the bankfull capacity of the channel downstream of Friant in subreaches 1A, 1B, and probably 2 was on the order of 12,000 cfs to 13,000 cfs (Q2) (Table 3.4. and Table 3.1). Even though the pre-Friant gage record at the Fremont Ford gage is short (11 years), the estimates of the magnitudes of higher frequency events is likely to be reasonable. The estimated pre-Friant bankfull capacity of the San Joaquin River in subreaches 4A, 4B, and 5 was on the order of 3,500 cfs (Table 3.4), which was about a 2-year event (Table 3.1). Based on very limited data, it appears that overbank flows occur under existing conditions at peak discharges between the 5-year and the 10-year events for most of the study area (Tables 3.1, 3.3., and 3.5). An exception may be between Mendota Dam and Sand Slough, where the hydrology is very poorly defined.

Because there are no in-stream flow requirements for the San Joaquin River and maintenance of riparian rights is required only as far downstream as Gravelly Ford, at least two subreaches of the river are dry (subreaches 2 and 4A) except under flood-flow conditions. Boyle Engineering (1986) estimated that a discharge of 35 cfs below Gravelly Ford for every day of the year (25,000 acre-feet per year) would be required to maintain a permanently wetted channel from Friant Dam to the Delta. Perennial flow conditions in subreach 2 would probably result in a strip of riparian vegetation along the low-flow channel margin in much the same manner as in subreaches 1A and 1B. This density of vegetation is unlikely to have adverse effects on the channel capacity; an appropriate hydraulic model could assess the actual effects. Base flow less than 35 cfs and for fewer than 12 months of the year would be likely to result in lower-density, patchy vegetation more similar to a summer-dry riparian corridor of an intermittent stream in an arid environment. Release of 35 cfs downstream of Gravelly Ford is unlikely to have much impact on sediment transport in subreach 2. Development of a perennial flow regime in subreach 4A downstream of Sack Dam would have the advantage from a flood conveyance perspective of reducing the amount of in-channel vegetation if the existing channel-bed vegetation was removed at the same time the flow regime was altered.

Mendota Water Importation

The hydrologic changes in the system have probably had their most visible impacts in subreaches 3, 4A, and 4B. The addition of Delta-Mendota Canal water at the head of the subreach has created a perennial flow regime between Mendota Dam and Sack Dam. The imported flows are supporting dense riparian vegetation along the channel margins, increasing the stability of the banks in areas where the vegetation is present. However, where vegetation is not present, a case can be made for increased bank erosion rates because, in general, the toes of the banks are composed of cohesionless sands that are readily entrained by moderate flows. Since the bed material in the reach is sand-sized (Table 4.7), the imported flows have the ability to transport a relatively large, but as yet unquantified, amount of sediment downstream toward Sack Dam. Moderated flood flows in subreach 3 (Table 1.1) do not have the scour potential to remove the riparian vegetation, but they do have the ability to transport to, and deposit considerable volumes of sediment in, subreach 4A, where there is no perennial flow regime.

Subsidence

Subsidence caused by groundwater overdraft appears to be having an adverse impact on the downstream elements of the Eastside Bypass system, but there is no unequivocal evidence that this subsidence is affecting the mainstem river and the sloughs (Tables 4.4, 4.5, and 4.6). Additional survey data would be needed to determine whether there has been any degradation in subreach 5, and if ground subsidence is affecting the frequency of overbank flows and, therefore, floodplain inundation.

The thalweg elevation has been lowered throughout subreach 3 (Table 4.5), but the lowering could have been due to both groundwater withdrawal–induced subsidence and release of sediment-free Delta water into the channel at Mendota Dam. Both potential causes could trigger the greatest amount of incision in the upper part of the subreach and lesser amounts further downstream. However, Ouchi (1983) was unable to detect the expected increase in channel sinuosity that should have accompanied the subsidence; he attributed the lack of channel response to reduced flood flows and, therefore, a lower potential for bank erosion because of upstream water storage and diversion of flood flows. It is possible that slope reduction expected to result from increased sinuosity (reduced channel slope) was subsumed by channel degradation, which would have the same effect. However, the channel depth data in Table 4.4 do not indicate widespread incision, but this could be the result of the limited number of cross section data points.

Flood Control Project

Distribution of flood flows into the Chowchilla Bypass, construction of local levees, and importation of Delta water have effectively resulted in reduced flood-carrying capacity between Mendota Dam and Sand Slough. Because there are only short-term hydrologic records from Fremont Ford gage prior to the construction of Friant Dam, it is unclear what effect the upstream water development and flood control system have had on the peak-flow frequencies downstream of Bear Creek. However, conveyance of flood flows in the bypasses to specific locations along the San Joaquin River mainstem undoubtedly has affected peak-flow frequencies in subreaches 4B and 5.

Construction of the flood control system in the late 1950s and 1960s significantly modified the distribution of the flood flows within the flood basin and in subreaches 3, 4, and 5. Where historically the flows debouched into the west basin at the head of subreach 4A, most floodwaters are now routed into the Eastside Bypass via the diversion canal at the Sand Slough Control Structure, thereby eliminating all flood flows from subreach 4B. Where historical flood flows entered the east basin at Lone Willow Slough (near the present-day Chowchilla Canal in lower subreach 2) and other sloughs downstream (e.g., the natural head of Sand Slough), most flow is now routed into the Eastside Bypass via the Chowchilla Bypass inlet and the canal at the Sand Slough bifurcation weir.

The bypass system now returns flows to the San Joaquin River at specific point locations at the confluence of Mariposa Bypass and at Bear Creek. The major increases in convergent river flow at these locations (Table 1.1 and Figure 1.1) is probably responsible for the increased cross sectional area of the San Joaquin River downstream of these locations (Table 4.4) and may also be responsible for much of the bank erosion.

From a practical point of view, the San Joaquin River has been rerouted at the Sand Slough Control Structure out of the historic river channel and into the Eastside Bypass at least as far downstream as where the Mariposa Bypass returns flow to the mainstem. Considerable vegetation has become established in the channel within subreach 4A because of the absence of a perennial flow regime and the relatively low magnitude of the floods. This vegetation appears to be supported by leakage from Sack Dam and from the channel-bounding canals and, possibly, by shallow groundwater. The in-channel vegetation increases the hydraulic roughness in subreach 4A and exacerbates sediment deposition, thereby affecting channel capacity. In subreach 4B, it appears that enough agricultural tailwater reaches the channel to prevent vegetation from establishing in the bed of the stream in some portions. However, very limited distribution of flood flows into the channel (300–400 cfs) has allowed the channel to narrow significantly between the Sand Slough Control Structure and the confluence with the Mariposa Slough (Table 4.4).

Subreach 2 from Mendota Dam to Gravelly Ford encompasses the head of the flood control system levees and the first major flow bifurcation into the bypass system. Base level control for this subreach is exerted by Mendota Dam and the Mendota Pool water level. Under flood flow conditions, the Mendota Pool, which is reported to be filled with sediment, causes upstream backwater that further reduces the sediment-transporting capacity of the very sinuous, meandering channel of the San Joaquin River (Table 4.2). Downstream of the Chowchilla Bypass Structure, the channel is essentially dry, except under flood-flow conditions, when about 2,000 cfs is passed downstream (Table 1.1).

Sediment deposition within the lower reaches of the Eastside Bypass has (1985/1986) required the removal of more than 1 million cubic yards of sediment (Corps 1993) to maintain the hydraulic capacity of that element of the flood control system. On-going sediment deposition is adversely affecting hydraulic capacities. Sediment deposition in the bypasses is the result of three principal causes:

- erosion of the eastside tributaries such as Ash Slough;
- erosion of the bypass channels themselves where shear stresses exceed the erosion resistance of the caliche-cemented, primarily sand-sized bed materials; and
- distribution of San Joaquin River sediments in proportion to the flow splits at the bifurcation structures.

The combined effects of the raised base level, backwater, and very high upstream sediment supply caused by bank erosion in the reach upstream of the bifurcation weir have resulted in aggradation of the river channel. This aggradation is evidenced by the presence of alternate sand bars throughout the high-amplitude meander bends. Considerable volumes of sediment, estimated to be 0.5 million cubic yards per mile, derived from bank erosion are stored in the bed of the channel upstream of the Chowchilla Bypass Control Structure. The sediment detention basin in the head of the bypass, with a capacity of about 1.5 times the project storm bedload yield (200,000 cubic yards), is filled within a 2–3 month period. Ten- to 15-feet deep sand and gravel extraction pits dug in the bed of the river between 1986 and 1995 by local landowners were filled in a single event in 1995.

Sand and Gravel Mining

Subreaches 1A and 1B extend from Herndon to Friant Dam; these subreaches have been severely affected by in-channel and channel-margin sand and gravel mining. Excess of extraction over supply to the reach between 1940 and 1996 has been estimated to be on the order of 1,255 million cubic meters (Cain 1997). What was historically a single-thread, low-sinuosity, meandering river has become a hydraulically disrupted flood conveyance system composed of single-channel segments, multi-channeled segments, and breached pits.

Study Area Vegetation Conditions and Trends

The consequence of reduced floodplain inundation frequency, depth, and duration is a significant reduction in the potential for riparian vegetation to establish on new surfaces through overland seed dispersal or rewetting of secondary channels, sloughs, and ponded depressions. For riparian vegetation, the effect of reduced bankfull discharge and reduced base flow is most acute in the spring months when cottonwood, willow, and sycamore seed is dispersed to potential growing sites on bars and floodplains. Throughout most of the study area, saplings or young trees were rare to absent on many floodplain surfaces that otherwise supported mature woodland types (i.e., little understory development). Where seedlings and small saplings were observed, they occurred within a narrow vertical range within 0.5–2 feet above the low–flow channel thalweg or water surface, even though the January 1997 flood stage range was considerably higher. (Note that although the January 1997 event is the flood of record for the post-Friant period, it was followed by very little precipitation during the remainder of the normal wet season. Riparian seed is primarily dispersed during the spring months or, for some species such as ash, in late fall.)

Given that the normal range of annual flows falls well below bankfull discharge in most years, channel scour and bank retreat are not anticipated to greatly affect the loss of existing riparian vegetation of any age class or cover type. Flows corresponding to estimated bankfull discharge and corresponding velocities at surveyed cross sections are 2–3 feet per second or less, which is within the normal range of resistance of riparian vegetation to hydraulic forces. Flood scour and uprooting of riparian vegetation observed in fall 1997 in subreach 1 and portions of subreach 3 are unlikely to occur with any significant frequency under current flood hydrology and operations; therefore, vegetation on bars is expected to recover over the next few years. On the other hand, the low energy associated with reduced flood flows has reduced bank migration and the development of accreting point bars within channel meanders that would otherwise be colonized by new riparian vegetation.

Conversion of riparian habitats to agricultural uses occurred over a large expanse of the historic riparian and marsh floodplains and basin lands of the San Joaquin River, but most of the areal extent of agricultural reclamation apparently predated the major changes in river hydrology caused by Friant Dam and the flood bypass system. However, within and along the riparian corridor closer to the active channel of the river and major sloughs, expansion of agricultural and urban development flanking the river, as well as more recent recreational land uses, have encroached further into the river floodplain in more recent decades. Further encroachment may continue in the future at a moderate rate in specific locations. Reduced risk of flood damage since the early 1960s (i.e., since completion of the flood bypass system) within the floodway and on undesignated floodplains may have inadvertently promoted replacement of remaining riparian habitats with commercial land uses of many types.

Channel clearing for flood control purposes is at most only a minor factor in limiting riparian vegetation in the active channel during the past 15–30 years. Some limited clearing within the low-flow channel may be needed in the future to maintain design flood flows in specific subreaches that have inadequate floodway capacity to protect major levees from flood damage caused by overtopping. The most constricted sites are where intermittent flow is found in combination with moist surface conditions on the channel bed during the growing season, thus promoting the growth of sandbar willow and giant reed across the entire channel cross section at some sites (primarily in subreach 4 and 3 below Sack Dam). However, riparian vegetation on floodplains flanking the active channel does not appear to be substantially affecting floodway capacity on most of the river, including in subreach 3. A comprehensive hydraulic model of the river is needed to assess flow capacity in river segments where a concern has been expressed about the ability of the channel to safely pass flood flows.

Boron and salinity levels in soils and shallow groundwater are potentially a limiting factor for the recruitment of riparian vegetation of upper subreach 3, lower subreach 4B, and subreach 5. The effects of this naturally occurring limiting factor may be magnified by groundwater overdraft east of the river and the near absence of overbank flow over most of the historic floodplain. These conditions may have reduced the natural dilution and erosion of concentrated surface salinity in the flood basin, on low-flow channel banks, and in intermittent sloughs and depressions.

In general, the geographic extent of potential future riparian vegetation is considerably smaller than the current distribution of mature riparian habitats. Existing mature riparian forest occurs over a greater vertical range associated with hydrologic conditions that preceded construction of local levees, the flood bypass system, and the canal and reservoir projects. The combined effect of multiple projects altered the hydrology of the river, reducing the magnitude of flows, which subsequently restricted the vertical range and geographic extent of alluvial processes that support riparian vegetation and promote its regeneration. In effect, many acres of mature riparian forest and valley oak woodland found today on higher, abandoned floodplains or on the "dry" side of levees is unlikely to be replaced in the future through natural regeneration processes as the stands dissipate with age.

Although large gaps are found in the presence or quality of riparian forest along the 150-mile study area, the remaining vegetated corridor supports a wide diversity of riparian habitat types, species mixes, and age classes. Large nodes of good-quality riparian groves, some with multi-tiered canopies and dense understories, can be found in many locations in all but subreach 2. Some of the areas with the least amount of existing riparian resources have some of the greatest potential for future restoration, including subreach 2 and along some of the former channels of the anabranched network (miscellaneous named and unnamed sloughs) in the floodplain of subreaches 4 and 5.

Reach-Specific Vegetation Conditions and Trends

Subreach IA and IB: Friant Dam to Gravelly Ford

Long-term removal of sand and gravel in the channel and floodplain, combined with loss of the upstream sediment supply, have caused degradation of the channel thalweg in subreach 1. Channel incision and pit capture generally increases the cross sectional area of the channel; greater discharge is therefore needed to reach bankfull stage and inundate the adjacent floodplains where riparian vegetation is commonly found.

This subreach supports nearly continuous riparian vegetation, except where the channel has been disrupted by instream aggregate removal or captured wet pits. The attenuation of peak inflows in the reservoir and the reduction in the frequency and duration of channel-scouring flood flows below Friant Dam have created more stable conditions in the active channel. Where the active channel was formerly dominated by riverwash deposits on large point bars and mid-channel islands, altered hydrology has promoted occupation of the bars and shoreline by alder, buttonwillow, willow, and ash. Continuous open water, created by a relatively uniform summer base flow and numerous instream mining ponds, appears to be the primary factor preventing greater encroachment of woody vegetation within the active channel.

The scarcity of mature vegetation on the backside of many point bars and on low floodplains in subreach 1B may represent the lasting effect of extensive removal of riparian vegetation by the Corps for floodway clearing performed in 1968 through 1970 between Gravelly Ford and Highway 41.

Historical changes in total acreage of riparian habitat are primarily attributable to expansion of mining in the channel and floodplain and to the lateral expansion of urban uses (e.g., golf courses) and vineyards flanking the river. Within the Corps-designated floodway along the river, lower probability of flows exceeding bankfull stage may have inadvertently encouraged encroachment of agricultural fields, recreational developments, and local levees onto lower floodplain surfaces previously occupied by riparian habitat.

Probable future conditions for riparian habitat in subreach 1A include stable growth on bars along the low-flow channel, with likely recolonization of bars exposed by extreme scour during the January 1997 flood. A gradual decline of old-growth woodland on abandoned floodplains can be expected along with a gradual loss of floodplain vegetation to expansion of wet pit mines and new golf course development. In subreach 1B, generally stable growth along the low-flow channel and recolonization of low bars exposed by the 1997 flood are also expected. A gradual loss of some low floodplain vegetation to further expansion downslope of vineyards and orchards is possible.

Subreach 2: Gravelly Ford to Mendota Pool

In most years (unlike 1997), the channel is essentially dry most of the year from Gravelly Ford to Mendota Pool, except under flood release conditions, when up to 2,000 cfs is passed downstream of the Chowchilla Canal bypass inlet. Only 5 cfs of instream flow is required at Gravelly Ford, which does not extend far downstream because of the porous bed substrate and high rate of percolation. The combined effects of backwater conditions above the twin wiers at the head of the Chowchilla Bypass, the low channel slope created by high channel sinuosity, and the backwater effect of Mendota Pool are responsible for the considerable aggradation of sand in this reach of the channel. Accumulation of sediment within the channel reduces flood conveyance capacity in this reach.

Vegetation in the upper 10 miles of this reach is sparse or absent, but the lower few miles support narrow, patchy, but nearly continuous vegetation where backwater forms upstream of Mendota Pool. Vegetation in this reach may also be supported by apparently shallow groundwater near the reservoir. The greatest extent of cottonwood seedlings was found in this reach in narrow rows along, and within 6 to 12 inches above, the low-flow water surface. Further upstream, the absence of predictable flow coincides with the near absence of vegetation in the active channel. The establishment of riparian vegetation also appears to be limited by the availability of shallow groundwater along most of this reach.

Historical changes in the total acreage of riparian habitat are primarily attributable to expansion of agricultural fields and vineyards, with a corresponding reduction in forest, scrub, and marsh vegetation. The reduction in flood frequency and scour potential along with less wetting of the channel and floodplain because of altered hydrology from Friant Dam and the flood bypass and levee system probably accelerated the rate and extent of agricultural conversion of the riparian meanderbelt. Conversion of the remaining floodplain found within the levees to annual and perennial crops precludes riparian habitat from recolonizing the low-relief topography. Excavation of sand in the river channel for private use by local ranches occurs at many sites in subreach 2, primarily upstream of Chowchilla Bypass. The already low potential for new stands of riparian vegetation to establish along this reach is even lower in areas that are skimmed for sand excavation.

Little change is expected in subreach 2 under current conditions. A possible exception is the survival and growth of numerous cottonwood seedlings established in 1997, but these may perish in dry to normal years without flow or shallow groundwater for prolonged portions of the dry season. A gradual increase of exotic trees and shrubs adapted to disturbance is possible in subreach 2, based on the presence of incipient stands and the known tolerance to drought and disturbance of these species. Further expansion of agricultural fields onto meander bend floodplains in lower subreach 2 is possible. Much of the remaining natural topography may be too flood-prone for most agricultural uses (except for livestock grazing) ,unless local levees are constructed within the bendways closer to the active channel.

Subreach 3: Mendota Pool to Sack Dam

At most surveyed cross section locations, the historical bankfull discharge of the channel varies but is rarely achieved under current conditions because of reduced flood flow. Urban development at Firebaugh, local levees, and the canals for agricultural irrigation water distribution that flank the river have further limited the its historical floodplain and the natural vegetation that formerly grew there.

Perennial conveyance of Delta water through the reach has promoted the development of riparian vegetation along the channel; such vegetation increases the resistance to erosion of the banks. Nearly continuous riparian vegetation of various widths and cover types occurs on at least one side of the channel within this reach. Continuous open water, created by a relatively uniform irrigation season base flow of imported Delta water, appears to be the primary factor preventing further encroachment of woody vegetation within the active channel.

Historical changes in riparian habitat include reduction in the extent of willow scrub and bare riverwash bar deposits in the active channel, replaced by a greater proportion of riparian forest along banks and riparian scrub on bars within the channel. Reduction of bedload below subreach 1 and reduced scour due to much lower flood frequency is likely to have caused this shift. A narrowing of the riparian corridor also occurred, primarily between 1937 and 1957, because middle to upper floodplain elevations were developed for agricultural uses and, in Firebaugh, some urban expansion.

Little short-term change is expected in subreach 3 under current conditions. A gradual aging of riparian scrub to forest types may occur along the channel where trees are left undisturbed by flood scour or channel clearing. A gradual decline of old growth cottonwood and oak forest on high ground because of age will occur. Smaller groves of trees will be lost to periodic spot fires and an additional increment of loss will possibly occur as a result of the expansion of agricultural fields onto idle pasture and woodlands inside of meander bends.

Subreach 4A: Sack Dam to Sand Slough Control Structure

For most of the year, subreach 4A is dry. In-channel vegetation is supported by flows or moisture derived from leakage or spillage at Sack Dam, from shallow groundwater, and, possibly, from seepage from the canals that border the river. The in-channel vegetation increases the hydraulic roughness in the subreach and exacerbates sediment deposition, thereby affecting channel flow capacity. Historically, this subreach of the river was an anabraching system with multiple channels in the overbank areas. Winter and spring high flows that were historically conveyed in the sloughs are now conveyed in the Eastside Bypass system.

This subreach is only sparsely vegetated and much of it is devoid of woody cover; the subreach is punctuated by narrow strands or patches of mostly willow scrub or small potholes with marsh vegetation. Primary factors in the reduced acreage of riparian-associated habitats include reduced hydrology (lower spring baseflow and lower bankfull discharge frequency and duration), levee and ditch construction that isolated backwater ponds and sloughs, and draining of large marsh areas. A very low rate of recolonization of riparian vegetation on overbank areas, attributable to infrequent inundation of floodplains and secondary sloughs and possibly higher concentrations of surface salinity, contributes to an overall gradual loss of woody cover as a result of the decline of existing mature willow-oak woodlands due to age. Flanking land uses, primarily intensive agriculture and private and publicly managed wetlands, also prevent reestablishment of riparian habitat on otherwise moist lowland surfaces and in remnant basins and swales.

Survival of established (mature) riparian vegetation does not appear to be affected by the intermittent flow regime. Full-canopied riparian scrub and forest occur in small to large stands, and ponds rimmed by small areas of marsh vegetation are present within the channel. This subreach is also reported to have shallower groundwater within 5 to 10 feet of the surface, and the water table may be exposed in places above the channel thalweg elevation. Extensive agricultural irrigation during the dry season close to the channel may also help sustain streamside plants. The moisture-holding capacity of soil is higher in this subreach because of the larger fraction of fine sediment (silt and clay) in the valley floodplain soils.

Under the existing, intensive level of agricultural operations close to the river in this subreach (primarily cotton crops) and the current hydrology, it is likely that no natural regeneration of riparian forest will occur in overbank areas. However, low floodplains along the channel and the presence of shallow groundwater may allow trees to reinvade the overbank area of any fields abandoned in the future, especially if a higher discharge of flood flows is again routed through this subreach. Within the active channel, further encroachment of willow scrub is possible in areas where groundwater is near the surface unless spot clearing of the channel is performed by local landowners.

Subreach 4B: Sand Slough Control Structure to Bear Creek

The Sand Slough Control Structure presently controls the distribution of flows between the river in this subreach and the Eastside Bypass. Between the Sand Slough Control Structure and the Mariposa Bypass, flood flows in the river are kept to as low as 300–400 cfs. The river channel below Sand Slough lacks the hydraulic capacity to pass higher flows without causing some local flooding of agricultural fields that have encroached onto low floodplain areas. In practice, the river has been rerouted at the Sand Slough Control Structure back into the Eastside Bypass at least as far down as where the Mariposa Bypass returns some flow to the mainstem river.

This subreach was historically an anabranched system, with the flows being divided between the meandering mainstem and multiple sloughs distributed throughout the expansive overbank area. Local levees and channel plugs now separate the distributary sloughs from flow in the river. Under existing conditions, attainment of sufficient discharge to achieve inundation of the channel margins depends on routing flood flows from the Eastside Bypass to the mainstem.

Upstream of the Mariposa Slough bypass, the river supports a nearly unbroken, dense but narrow corridor of willow scrub or young mixed riparian vegetation on most of the remaining subreach, with occasional large gaps or patchiness in the canopy. Reduced hydrology (lower spring baseflow and lower bankfull discharge frequency and duration), levee and ditch construction that isolated backwater ponds and sloughs, and draining of large marsh areas appear to be the primary factors in the reduced acreage of riparian-associated habitats. A very low rate of recolonization of riparian vegetation on overbank areas, attributable to infrequent inundation of floodplains and secondary sloughs and possible higher concentrations of surface salinity, contributes to an overall gradual loss of woody cover from the decline of existing mature willow-oak woodlands due to age.

A gradual decline of old-growth willow and oak as a result of age can be expected along the river and major sloughs in subreach 4B, as well as in inactive slough channels. Some increase of patchy willow scrub is possible within the active channel on low bars because of recent recruitment of seedlings and saplings in the past 1 to 3 years. An encouraging new sign of regeneration potential along the river, observed during field surveys in September 1998, is the presence of vigorous willow saplings growing on low, moist sand bars within the active channel downstream of the Mariposa Slough confluence. More extensive post-flood recovery of riparian habitats may be restricted by boron and salt toxicity in shallow groundwater, especially along abandoned slough channels and other depressions.

Subreach 5: Bear Creek to Merced River

The frequency of overland flow beyond the natural channel banks is measurably increased in this subreach, which is downstream of inflows from two bypasses and several eastside tributaries. However, inundation of the floodplain is still less frequent than occurred before construction of Friant Dam. Comparison of cross sections shows that the channel has both widened and deepened in the area where a significant portion of the flood flows from the Eastside Bypass are discharged back into the mainstem river.

The river in this subreach is surrounded by large expanses of upland grassland with numerous inclusions of woody riparian vegetation within the floodplain. The floodplain and basin are generally disassociated from the mainstem river, with remnant tree groves concentrated on the margins of mostly dry secondary channels and depressions or old oxbows. Along the mainstem river, a relatively uniform pattern of patchy riparian canopy hugs the channel banks in the form of large individual trees or clumps (primarily valley oaks or black willow) with a mostly grassland understory. The 1938 aerial photographs exhibited a similar patchy pattern of vegetation, but with greater total woody cover, a higher proportion of mixed riparian vegetation relative to scrub, and large expanses of herbaceous riparian vegetation and marsh clustered along the river and sloughs. These features are no longer present.

Boron and salinity levels previously recorded in soils and shallow groundwater in this area are potentially a limiting factor for riparian vegetation in this subreach. Portions of bars and banks at lower elevations tend to show the effects of salt accumulations, which may limit regeneration by suppressing seed germination or seedling survival.

Future conditions will be the same as in subreach 4B (described above), but these apparent trends also apply to remnant riparian corridors along Mud and Salt Sloughs. Any future changes in the discharge or quality of base flow in either of these two major sloughs as a result of improved water supply for refuge management may result in modest benefits to riparian habitat regeneration along the channels. However, the poor quality of shallow groundwater and the absence of more frequent overbank flows may continue to limit vegetation regeneration. An encouraging new sign of regeneration potential along the river, observed during the September 1998, field surveys, is the presence of vigorous willow saplings growing on low, moist sand bars within the active channel in the understory of old-growth willow trees.

Recommendations to Improve Riparian Habitat and Channel Stability

The following sections describe general restoration opportunities and constraints and potential restoration strategies on the San Joaquin River. Some site-specific restoration concepts along subreaches 1 and 2 are also suggested. Restoration strategies are intended to make progress toward riparian habitat expansion and enhancement and river stability given the opportunities and constraints identified.

Improving riparian habitat quality and extent on the San Joaquin River involves three broad categories of restoration approaches:

- ✦ **Conservation** and stewardship of existing riparian habitat, associated resources and physical processes, and large habitat nodes.
- ✦ **Management** of land use and flows along the 150-mile river corridor to promote physical processes that lead to natural regeneration of riparian vegetation.
- ✦ **Restoration** projects (grading, seeding, and planting) at specific sites where riparian habitat is unlikely to regenerate naturally, but will survive and mature once plants become established.

Each of these restoration approaches is discussed below and specific restoration measures are recommended.

Conservation of Existing Resources

1. Protect existing riparian habitat in subreach 1 at risk of loss to mining expansion

This approach would involve creating incentives to encourage mining companies to phase out mining in the active channel and lower floodplain of the river. Extensive aggregate deposits are available to be mined in terrace deposits flanking subreach 1, and other possible sources of aggregate include the aggrading deltas formed where rivers and tributaries enter the foothill reservoirs of the San Joaquin Valley. Incentives could include land exchanges, purchase of mining rights, transfer of mining rights to less sensitive sites, reduced tonnage fees on aggregate mined outside the riparian corridor, and expedited approval of mine permits outside the riparian corridor. Local jurisdictions could promote development of reclamation plans for mines with existing permits that would require wider setbacks for deep pits along the active channel and the filling of breaches between the natural river channel and deep wet pits.

2. Establish a river meander corridor between Chowchilla Bypass and Mendota Pool

This subreach has the highest sinuosity in the study area and a greater tendency for bank migration, bendway cutoffs, and overbank flows across the meander bends. This approach would involve establishing a river meander zone in this subreach and creating positive incentives to encourage agricultural landowners to remove or set back local levee segments and access roads within the sinuous bends. This approach is necessary to allow river bends to migrate (i.e., erode and deposit) within a designated meander corridor and allow high flows to overtop the large point bars. These alluvial processes will promote regeneration of riparian vegetation and overall habitat complexity. This concept would require hydraulic analysis and improvement of a "back-up" levee system that would represent a firm line of defense for adjoining agricultural fields against high water and channel migration. The approach would also involve protecting existing riparian habitat and natural topography within the meanderbelt through the purchase of fields within bends (or easements and land exchanges) or other cost-share incentives to support landowners who voluntarily idle fields or protect riparian habitat within the meander zone.

3. Conserve existing natural sources of river gravels below Friant Dam

Dry Creek enters the river below the dam and is the only remaining tributary that supplies a significant source of coarse sediment with high flows. Bedload entering the river from Dry Creek during high flows reduces the tendency of the channel to incise and forms shifting riverwash deposits on bars that are needed for riparian colonization and succession to occur. Programs and incentives discussed in conservation measures 1 and 2 above could be employed to conserve the natural sediment supply on Dry Creek and other important sources of coarse sediment.

4. Protect existing riparian floodplains from encroachment of incompatible land uses within the floodways

This approach would require encouraging local jurisdictions to clarify the boundaries of designated floodways along the river and inform landowners about the risk of periodic flood damage to perennial crops and golf courses on lower floodplain surfaces. It would also involve encouraging landowners to preserve the remaining riparian habitat on lower flood surfaces and would avoid the need to place expensive riprap on banks that would otherwise support natural growth. Where voluntary conservation may not be working, it may be necessary to protect existing habitat and natural topography within the floodway through purchasing low-lying fields (or easements and land exchanges) or other developing cost-share incentives to support landowners who may have temporarily idled flood-damaged orchards and vineyards or low-level portions of country club landscaping.

5. Conserve remaining natural floodplain topography and sloughs

Large areas of the historic floodplain in subreaches 3, 4, and 5 still support natural topography and sloughs (anabranched channels) on both sides of the levee network, while other areas have been laser-leveled for irrigated agriculture or managed wetlands. Canals, roads, and ditches may criss-cross the natural topography, but some of these areas (on both public and private lands) have potential for returning natural overbank flows or reconnecting former and abandoned channels and sloughs to convey natural floodwaters. The potential for rewetting the floodplain varies by reach, based on the changes in bankfull channel capacity and the magnitude of the reduction of flow under current hydrology compared to conditions under which the floodplains were formed. However, many areas would derive ecological benefits from the reintroduction of managed or natural overbank flows (generally within a range of average annual to 10-year frequency inundation).

Existing state and federal land and wetlands management incentive programs and set-asides could incorporate additional incentives or qualifying guidelines that promote the conservation of the natural topgraphy and drainage network of the San Joaquin River in the study area. Corridor flood easements, removal of earthen plugs where feasible, and land acquisitions could also be included to reestablish the connectivity of the river with historic sloughs in the overbank areas. These measures offer the added benefit of potentially significant increases in the overall flood-carrying capacity of the river and temporary flood water storage in the overbank plain and sloughs, thereby reducing the flood stage along the levee system.

6. Develop special conservation programs to protect large remnant stands of old growth riparian woodlands

Old-growth stands of cottonwood forest, sycamore and valley oak woodland, and wooded grassland savanna are scattered throughout the study area. Some of these stands occur within state and federal refuges or parks, while others are found on private lands. Landowners at these sites should be contacted to determine if the old growth sites are secure under existing land management or if special conservation easements or management plans (e.g., wildfire response plans) are needed to ensure the long-term survival of these unique relict-age classes and their wildlife habitat and aesthetic values.

Management of the River Corridor

1. Maximize wet year flood flow releases

Current flood operations practice and guidelines typically result in uniform flows for long durations during the winter and spring months. However, it may be possible to optimize riparian ecological and geomorphic benefits by modifying flood operations guidelines and schedules in wet years to include more variable hydrographs with higher peak flows of shorter duration and more overall variability of flows to increase habitat diversity, mobilize bar material, and create better seed dispersal and more favorable sites for colonization by riparian trees. A particular emphasis should be placed on flow peaks during at least portions of the early spring months when seed of cottonwood and sycamore trees is being dispersed in the river. The purchase of easements or fee title on lands that become subject to greater flood frequency from peak overbank flows could be used to expand the area of low floodplain along the river to be colonized naturally or planted with riparian vegetation. This measure offers the added benefit of increasing the operational flexibility of floodwater releases below Friant Dam without risking incidental damage to land improvements that have occurred within the floodway corridor.

Alteration of the flood flow regime to provide overbank flows to support riparian vegetation, although intuitively attractive, presents many practical challenges that may be difficult to overcome. Sediment is distributed in proportion to the flows at the double weir of the Chowchilla Bypass Control Structure, and, therefore, passing of additional flood flows down the San Joaquin River channel may increase the rate or volume of sedimentation in the reach. Increased sediment deposition in the area where the transport capacity is low due to the high sinuosity and where it is further reduced by backwater from the Mendota Pool may cause increased flooding, unless other measures are taken to improve sediment transport capacity or reduce sediment input.

The three primary control points to consider in modifying the flood hydrographs of segments of the San Joaquin River are:

a. **Friant Dam releases (affects subreach 1 and upper 2).** This would involve modifying reservoir flood storage pool releases to create greater hydraulic and stage diversity in the channel below the dam. A comprehensive hydraulic and sediment transport model can be used to evaluate the effects of modified flood hydrology (to benefit riparian habitat) on gravel and sand transport and bank stability in the river and to ensure that peak flows are compatible with the integrity and freeboard capacity of state and local levees. The hydraulic model would reveal conditions and sites downstream of Friant Dam where floodway encroachments or reduced channel capacity may constrain the operational flexibility of dam releases. The next step would be to evaluate the feasibility and cost of removing or modifying floodway encroachments or taking measures to increase channel capacity and operational flexibility to safely vary peak flows of moderate flood events.

b. **Chowchilla Bypass Bifurcation Dam flow splits (affects subreach 3 and lower 2).** This would involve evaluating alternative flow bifurcation rules at the inlet to Chowchilla Bypass, including passing a greater percentage of moderate flood discharge into the natural channel in subreach 2 below the double weir facility. Large flood events such as in 1986 and 1997 should continue to be routed primarily through the bypass system as designed, but moderate flood peaks, potentially exceeding 2,000 cfs for short durations, could be managed at the weirs to create more diverse flows and contribute to greater habitat complexity in subreach 2 and 3. A comprehensive hydraulic and sediment transport model is needed to evaluate the effects of modified flow splits on sand transport, channel aggradation, and bank stability in the river and to ensure that managed peak flows are compatible with the integrity and freeboard capacity of local levees. Some modifications in the cross section or alignment of constricted segments of local levees may be needed to implement this measure.

Weirs at the bifurcation could be operated to pass sediment-laden flows *under* the gates into the bypass, but *over* the gates on the San Joaquin River (i.e., to pass a lower concentration of suspended sediment down the river channel in lower subreach 2). However, the system-wide problem of sediment aggradation in low-gradient channels must be addressed in the bypass, the river, and Mendota Pool.

c. **Sand Slough Control Structure flow splits (affects subreach 4).** This would involve increasing the proportion of flow in subreach 3 that continues down the natural channel in subreach 4 via the Sand Slough weir and screw gates. A comprehensive hydraulic model is needed to evaluate the effects of modified flood hydrology on channel capacity and overbank flooding in subreach 4 and to ensure that peak flows are compatible with the integrity and freeboard capacity of state and local levees. The goal should be to at least manage periodic moderate flood peaks below Sand Slough equal to the original Corps design standard of 1,500 cfs and to evaluate the feasibility of higher flow splits. Flow exceeding floodway design capacity would require purchasing flood easements on low-lying land bordering the channel in subreach 4A and possibly modifying some local levees.

2. Manage "nursing" flows in wet year cycles to optimize seedling establishment and survival

Because there are no in-stream flow requirements for the San Joaquin River and maintenance of riparian rights is required only as far downstream as Gravelly Ford, at least two reaches of the river are dry (subreaches 2 and 4A) except under flood flow conditions. Boyle Engineering (1986) estimated that a discharge of 35 cfs below Gravelly Ford for every day of the year (25,000 acre-feet per year) would be required to maintain a permanently wetted channel from Friant Dam to the Delta.

Because riparian trees live from 50 to over 100 years, riparian habitat does not require successful colonization every year to maintain good distribution, continuity of canopy, and age-class diversity. Greatest recruitment generally occurs in years when high, scouring flows are followed by moderate spring weather with sustained base flow or persistent shallow groundwater. Reservoir and canal operations could be evaluated to determine the feasibility of releasing (from Friant and Sack dams) sustained spring base flows every 5–10 years to nurse seedling and sapling crops that are observed following winters with major flood events (e.g., as seen in subreach 2 in 1997). This concept is likely to have the least effect on storage for water supply if it is timed to coincide with multiple-year cycles of above-average runoff, high snow loads, and winter-spring spillage flows, which create good conditions for seedling dispersal to germination sites.

Presumably, irrigation demand is lower when these conditions coincide, and possibilities for conjunctive use of abundant groundwater is also greatest. A pilot project could be initiated to track the survival of cottonwood seedlings in subreach 2.

Augmented flow conditions in subreach 2 would probably result in a strip of riparian vegetation along the low-flow channel margin in much the same manner as occurs in subreaches 1A and 1B. That density of vegetation is unlikely to have adverse effects on the channel capacity; this conclusion could be assessed with an appropriate hydraulic model. Base flow less than 35 cfs and for fewer than 12 months of the year would be likely to result in lower density, patchy vegetation more similar to a summer-dry riparian corridor of an intermittent stream in an arid environment. Release of less than 35 cfs downstream of Gravelly Ford is unlikely to have much impact on sediment transport in subreach 2.

3. Establish a perennial flow regime in subreaches 4A and 4B downstream of Sack Dam

Development of a perennial flow regime in subreaches 4A and 4B downstream of Sack Dam would have the advantage from a flood conveyance perspective of reducing the amount of in-channel vegetation if the existing channel bed vegetation were removed at the same time as the flow regime was altered. San Luis Refuge could possibly convey some of its allocated water down the San Joaquin River below Sack Dam and then build an intake pump station downstream to supply adjacent wetlands. Other downstream water users with firm surface water contracts could also potentially exchange a portion of canal-supplied water for a comparable amount of water released to and then diverted from the river channel farther downstream. In-channel water losses to bed percolation would be relatively low because of the high water table and local tailwater and canal seepage occurring on one or both sides of the channel.

4. Reduce sediment sources entering the river and bypass system

Sediment deposition within the river and bypasses is a recognized problem. The potential for aggradation of sand in the river bed is a serious constraint to revegetation of riparian habitat in some river segments where floodway capacity is inadequate under existing conditions. However, much of the sediment appears to be generated by erosion within the bypasses and some of the eastside tributaries (e.g., Ash Slough). Therefore, reduction of the sediment problem requires solution of the erosion problem within the bypasses and on the eastside tributaries entering the Eastside Bypass. Hydraulic analysis of the stability of the bypasses where the caliche cementation has been breached may indicate the need for grade control within certain reaches. Bed and bank protection or better erosion-control management of the tributary channels and watersheds also may be required in one or more tributaries to reduce sources of sediment.

5. Eradicate or suppress populations of exotic, invasive trees and shrubs

Expansion of giant reed (Arundo), tamarisk, and eucalyptus in some river segments threatens riparian habitat diversity and quality; because of their growth characteristics, expansion of these invasive, non-native species will reduce channel floodway capacity and increase bank instability. This measure would involve initiating a program to map and thenceforth monitor the distribution of these species. In vulnerable subreaches with small, incipient populations (e.g., subreach 2), immediate eradication may be a cost-effective strategy. Where large stands occur, suppression and selective removal may be more feasible and less destructive to other habitat values. Effective new techniques have been tested and documented in recent years that combine innovations in low-impact, mechanical removal (e.g., onsite mulching of Arundo canopy volume) or prescribed fire with low concentrations of selective herbicides compatible with aquatic environments.

6. Develop and implement wildfire reduction plans for vulnerable riparian areas

Riparian vegetation (unlike invasive riparian exotics) lacks tolerance of fire and recovers poorly or not at all from hot fires. Fires in riparian environments are caused in many unrelated ways, including loss of control during prescribed burns for agricultural or levee maintenance, illegal campfires, and ignition of understory grasses by vehicle exhaust pipes or careless smokers; in addition, fire are sometimes deliberately started to remove riparian forest biomass. Fires in riparian areas are often considered low priority for local fire districts with small budgets and large rural service areas. This measure would require developing riparian fire response plans and guidelines and providing funding support to local districts and landowners in vulnerable areas (e.g., near major public access points). The California Department of Forestry and Fire Protection should be involved in implementing this measure.

Concepts for Restoration of Suitable Sites

Restoration of riparian vegetation may involve seeding and planting projects or modifying channel and floodplain topography to enhance natural fluvial processes that promote plant establishment and survival.

1. Rewater abandoned secondary channels and sloughs

Some of the most promising revegetation opportunities in the study area occur along the margins of abandoned secondary channels and sloughs that no longer receive periodic flow from the river at higher stages. The reasons for lack of intermittent flow vary, including channel incision, lack of overbank flood flow, placement of local levees, or plugging of the channel with small weirs or earth dikes to obstruct flow or provide local access roads on farms and wildlife refuges. Natural secondary high-water channels at bendway cutoffs tend to occur most in subreach 1 (e.g., Rank Island) and to a lesser degree subreach 2. Low-gradient sloughs and unnamed anabranch channels criss-crossing the east and west flood basins are found primarily in subreaches 4B and 5.

Opportunities exist for the rewatering of some of these channels, or portions of them, using one or more of the following measures (measures for flood flow management described in the above section will also enhance rewatering measures):

a. **Regrade secondary channels to receive a greater frequency of flow.** This measure would involve investigating the feasibility of excavating the beds of secondary channels to receive split flow during normal high water events; this recommendation applies primarily in subreach 1 to compensate for irreversible channel incision. At some sites, it may be a feasible option to import coarse bed material from adjacent high gravel and cobble bars or mine reclamation sites and raise the bed of the primary channel nearer to the thalweg of the secondary channel; however, this measure would probably require semi-permanent grade control structures to prevent re-incision of the channel bed.

b. **Remove up-channel obstructions to incidental flow opportunities.** At some sites, channel plugs and road crossings or past sedimentation may be obstructing through-flow from higher stages in the river. This measure would require investigating whether current land use and land use practices may have changed to be flexible enough to allow the rewatering of these isolated channels. In some cases, removing channel obstructions may require the negotiation and purchase of flood easements and agreements for riparian conservation corridors along these historic channels that pass through farmland, rangeland, or managed wetlands and public refuges. Of particular importance is the opportunity to reestablish periodic overbank flow that would enter the upstream end of the Salt Slough complex in the vicinity of the Pick Anderson Bypass or identifying other feasible left bank locations for flow splits to occur. Implementing this concept would requires greater knowledge of local topography, land management, and hydraulics of the floodplain to determine if and where reconnection of basin sloughs may be feasible.

2. Evaluate feasibility of removing specific levees separating the river from portions of its natural floodplain.

This measure involves removing site-specific local levees or deauthorizing unneeded segments of state levees to expand the area of flood basin, floodplains, and where natural sloughs are found. Similar to Measure 1.b, this measure would require more information about local conditions and site-specific approaches. This concept is being investigated by the San Luis Refuge along the river in the vicinity of Bear Creek on former agricultural and range lands recently acquired by the refuge. A subreach hydraulic model (UNET) and sediment transport analysis will be used to evaluate the feasibility of breaching or removing levees or constructing controlled release weirs to restore periodic inundation of the flood basin and rewater formerly abandoned channels outside the existing levees.

Sediment accumulation and vegetation encroachment in subreach 4B between Sand Slough and the Mariposa Bypass have so reduced channel capacity that release of flows in excess of 400 cfs into the mainstem channel at the flow bifurcation may cause overbank flooding of adjacent fields. Modification of existing levees (e.g., setbacks, notched weirs, or passive breaches) in the vicinity of Bear Creek at San Luis Refuge would permit some overbank flow into undeveloped natural areas (Great Valley Grasslands State Park, San Luis National Wildlife Reservoir) with the existing flow regime.

3. Evaluate feasibility of constructing new river channel to bypass Mendota Pool and dam

Continuity of a more natural channel flow and sediment transport between reaches 2 and 3 could potentially be achieved with a bypass channel around the east flank of Mendota Pool and the new dam. This measure would restore continuity of the riverine environment and the habitat connectivity of the riparian forest canopy. Inspection of the 1914 CDC maps of this area and old aerial photographs indicate that prior to construction of the north bank levees in subreach 2, several large sloughs conveyed right overbank flow in a northwesterly direction flowing toward and through the eastside basin. However, serious new risks or uncertainties would be involved with implementation of this measure and private land would be affected.

The river will adjust to any change in channel length and gradient and resulting changes in the energy potential of flood flow. Channel incision and lateral bank migration would be likely to follow any increase in the slope of the river thalweg. Engineered grade-control drop structures and new levees would be required along with the purchase of land and easements to ensure the stability of a new channel section and avoid channel erosion from headcutting upstream in reach 2. Determining the feasibility of this concept would require a detailed hydraulic and sediment transport analysis, including evaluation of bed scour potential. An important additional benefit of this idea would be significant reduction of sediment loading in Mendota Pool, but more sediment could be delivered to reach 3 and further downstream. In effect, the problem of high levels of sedimentation in the San Joaquin River remain, even if measures are taken that redistribute or concentrate the volumes of sand in ways that are potentially easier to manage.

4. Improve floodway capacity in subreaches 2 and 3 to make room for increased habitat and to reduce flood risk

In subreach 3 between Mendota Dam and Sack Dam, local levees may be having an adverse influence on flooding at Firebaugh. Local field levees impinging into the floodway within larger "setback" levees also occur in Reach 2 below the bifurcation dam. Release of higher flood flows into these reaches without a better understanding of the reach hydraulics and true floodway capacity could lead to flooding problems and increased bank erosion and, hence, sediment generation. A greater extent of overbank flows may be attainable in these reaches, even with the existing flood flow splits, if local levees could be removed or set back and flood easements attained from local landowners. This would have the additional benefit of improving hydraulic capacity and reducing flood stage around Firebaugh and upstream of Mendota Pool. In subreach 3, an obvious "back up" levee system already exists where levees bordering the major canals (e.g., Poso and Columbia canals) flank the natural river terraces, but these levees may need to be enlarged or upgraded to prevent any future overtopping or damage from wave erosion during high water events within the floodway.

5. Revegetate low floodplains formerly cleared for agricultural purposes or during past floodway clearing projects

There are many sites in the study area where low floodplains along the channel are subject to inundation at least every 5–10 years. The Corps' comprehensive new hydraulic model of the entire river and bypass system (in preparation) may reveal segments of designated floodways where actual capacity exceeds design capacity and can therefore safely convey large flood events, even with an increase in channel roughness (i.e., with more natural vegetation). In other cases, forest may have been cleared within a meander corridor for agricultural use, though many sites on agricultural fields appeared (on aerial photographs) to be abandoned or to have suffered recent flood damage. Low-elevation sites (relative to the channel thalweg or water table) are more likely to sustain planted vegetation after 1–5 years of temporary irrigation, depending on local soil and hydrologic conditions. Planted species mixes should conform to the vertical range of cohorts in the general vicinity of the river corridor.

6. Revegetate fields saturated by shallow groundwater

Aerial reconnaissance revealed fields in some areas that appeared to have a problem with persistent shallow water tables; some of these fields may have been recently abandoned or idled. Many of the sites, the size of which varies from small to large, occur outside of the levees flanking the river. However, they could easily support dense riparian forest if acquired for seeding or planting projects. (An excellent example of this type of opportunity is found adjacent to the northeast bank of Mendota Dam, where an apparently idled field with a shallow water table reverted back to dense, multi-species riparian forest.) Observation of color aerial photographs and groundwater contour maps of the study area suggests shallow groundwater conditions under low-lying fields may be common in the vicinity of the river in subreaches 3, 4A, 4B, and lower 2 near Mendota Pool reservoir.

7. Redirect mine reclamation guidelines and master plan projects to enhance and connect riparian habitat

Apparently no master plan exists for the coordinated reclamation of active and abandoned mine sites along the river in subreach 1. The extent and depth of open wet pits within the river channel and active floodplain may preclude complete restoration of a more natural river channel. However, opportunities exist to reconfigure some areas to favor a more flowing riverine habitat and improve the connectivity and quality of riparian forest and scrub adjoining the river channel and on secondary channels. By developing a conceptual reclamation master plan of the river corridor in this subreach, future mine reclamation and other restoration projects will be more compatible and mutually beneficial. Some counties set aside a portion of aggregate tonnage fees to fund river restoration projects.

8. Plant cottonwood cuttings along moist banks to close gaps in the riparian canopy

Connectivity of the riparian canopy is an important habitat characteristic for many riparian-associated native bird species and may be important to the quality of aquatic and semi-aquatic habitat conditions (for shade, cover, and food supply). Past disturbance and management practices have created gaps in the canopy along the river in many areas. Even in subreaches with perennial flow, dense stands of weedy herbaceous growth along the shoreline may be preventing the establishment of native trees. The potential exists to reestablish a continuous canopy by planting gaps with rows of cottonwood and willow cuttings or nursery plants; at sites where persistent soil moisture is close to the surface, irrigation water may not be needed for these plantings. The ideal time to acquire and plant cuttings is during winter dormancy, before the break of buds in early spring.

9. Initiate revegetation training seminars and technical assistance for local landowners

Local conservation districts in other counties (e.g.,Yolo County) have for several years sponsored seminars for and provided technical assistance and planting materials to local landowners who choose to implement their own habitat restoration projects. These programs have been very successful with private landowners who prefer to control their land and conservation priorities, but appreciate the access to technical information, walking tours of successful projects, and practical approaches by others like themselves. A similar program would be very successful on private lands in the San Joaquin River study area. Funding assistance should also be considered and may be available through existing programs under the Natural Resource Conservation Service, the federal Fish and Wildlife Conservation Fund, CALFED, and the riparian habitat program of the state Wildlife Conservation Board.

Site-Specific Restoration Constraints

Site-specific restoration constraints apply to specific places where one or more limitations to the restoration strategies described above may be present. Limitations may include cost, feasibility, or the magnitude of benefit of a particular restoration measure and should be considered before preceding with a site-specific plan.

Constraints Affecting Restoration Project Sites

Project sites considered for restoration should be evaluated for the presence and magnitude of constraints that may determine project success or influence the selection of measures implemented to overcome constraints. Potential restoration project site constraints include:

- Lack of flood flows that reach bankfull discharge and lack of floodplain inundation.
- Lack of flow or infrequent wetting of sloughs and anabranch channels in overbank areas.
- Prolonged periods of no flow (and lack of shallow groundwater) during the dry season in combination with coarse substrate.
- Channel incision and entrenchment and, possibly, related lateral instability.
- Potential for excessive vegetation encroachment in the active channel in the absence of high, scouring flows or persistent base flow.
- Reduced or inadequate flood-conveyance capacity in the river segment and, possibly, a need for channel clearing in the future to maintain minimum floodway capacity.
- Potential river capture of abandoned, wet gravel pits and resulting channel avulsion or abandonment of secondary channel flow.
- Effects of adjacent urban uses and users on the riparian zone (e.g., wildfire, off-road vehicle use, or vegetation thinning to improve river views).

- Potential for expansion of adjacent land uses or infrastructure into the riparian zone.

- Evidence of salinity in surface soils or shallow groundwater that may be high enough to prevent seedling survival or may suppress growth or vigor of larger trees and shrubs, particularly with the absence of periodic flooding.

- Potential for competition of native species with invasive exotic plants.

- Unsuitable soil conditions.

Soil Suitability Criteria for Selection of Project Sites and Measures

From a riparian vegetation perspective, soil mapping units and their corresponding landscape position can provide guidance in determining a vegetation association that might be suited for restoration at a given site. For example, Columbia soil mapping units occur in low and high floodplains and historically supported riparian scrub, mixed riparian, cottonwood riparian, and valley oak riparian forests. Hanford soils also supported cottonwood and willow riparian forests but, for the most part, supported extensive tracts of valley oak riparian forests on the higher positions of the floodplains and on natural levees. Many basin soils supported historic marsh land and open water with very fine-textured surface deposits that may not be suitable for growing trees and shrubs in the absence of frequent flooding or ponding under current hydrology.

While soil mapping units and landscape position provide a historic perspective of predisturbance vegetation patterns, the disruption of natural flooding patterns and floodplain ecological processes caused by altered surface and groundwater hydrology may render historic riparian soils unsuitable for restoration to the original historic natural vegetation type. Soils listed in Table 6.1 were correlated as historically supporting Great Valley riparian vegetation communities. However, due to alterations in the floodplain, the list has been modified to represent potential current restoration suitability. Also, although a soil may be listed as a riparian soil, it may be more suited for restoration of a valley oak woodland or savanna rather than a cottonwood riparian forest. A fine grain separation of specific riparian vegetation associations was not attempted at this macro-level. The list in Table 6.1, broken down on a county-by-county basis, separates soil mapping units into potential riparian soils, upland soils (grassland and oak savanna), and basin soils (seasonal wetland or emergent marsh).